

The University of Chicago

CALENDAR REFORM
IN THE THIRTEENTH CENTURY

A DISSERTATION SUBMITTED TO THE FACULTY OF
THE DIVISION OF THE HUMANITIES IN CANDIDACY
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF HISTORY

1932

By

MARY CATHERINE WELBORN

Private Edition, Distributed by
THE UNIVERSITY OF CHICAGO LIBRARIES
CHICAGO, ILLINOIS

1935

The University of Chicago

CALENDAR REFORM
IN THE THIRTEENTH CENTURY

A DISSERTATION SUBMITTED TO THE FACULTY OF
THE DIVISION OF THE HUMANITIES IN CANDIDACY
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF HISTORY

1932

By

MARY CATHERINE WELBORN

Private Edition, Distributed by
THE UNIVERSITY OF CHICAGO LIBRARIES
CHICAGO, ILLINOIS

1935



TABLE OF CONTENTS

Chapter	Page
I THE IMPORTANCE OF MEDIEVAL <u>COMPOTI</u>	1
II THE ECCLESIASTICAL SYSTEM OF TIME RECKONING	6
III SOME EARLY MEDIEVAL COMPOTISTS.....	13
IV SCIENCE IN OXFORD BEFORE THE TIME OF ROGER BACON.....	18
V AN ANALYSIS OF GROSSETESTE'S <u>COMPOTUS</u>	24
BIBLIOGRAPHY.....	34



Digitized by the Internet Archive
in 2026

https://archive.org/details/IA41548403_0023

I. THE IMPORTANCE OF MEDIEVAL COMPOTI

To a modern reader the word compotus¹ is undoubtedly a little known term, but to those who lived in the Middle Ages it was a household word. To study or to write a compotus was a task often assigned to school boys; it was also one of the chief vehicles for the mathematical astronomy of the scientists and pseudo-scientists.

From medieval writers, who never failed to start their discussions without first defining their terms, we learn that a compotus is a treatise which teaches three methods of time-reckoning; i.e. by the movements of heavenly bodies, by human authority, and by custom.²

No student in the Middle Ages, following his course of studies in the monastic or cathedral schools, or later in the universities, was allowed to omit the study of some sort of a treatise on this subject. St. Augustine (354-430), bishop of Hippo, is frequently quoted by medieval writers as saying that the compotus was one of the seven books which all priests must know; for instance in the Compotus of Gordianus,³ "Habet testatur Augustinus .4. in domo Dei necessaria scilicet grammatica, musica, ius canonicum, et compotus." Charlemagne insisted that the students in the palace school and in the monasteries should include the compotus in their list of studies;⁴ and, still later, the Oxford students who were preparing for a degree in arts were required to promise on the Gospels that they would devote so many terms or weeks to certain subjects, including "eight whole days exclusive

¹From Computare meaning "to reckon."

²For Grosseteste's definition, Compotus, Chapter I. It is interesting to compare this with the statement of Cassiodorus as given in his Institutiones (Migne, Pat. lat. XII, 1105-1120) "Ablatio computi est in qua astronomi secundum astronomicas regulas computantes, computum a computo iudicant auferendum." Also see Roger Bacon, Compotus, 2, in Opera hactenus inedita Rogeri Baconi, Fasc. VI, ed. by Robert Steele (Oxford, 1926).

³Anonymous Massa compoti, Vespasian A II, British Museum; also in Compotus Gordianus, MS. Vindob. 5239. What little is known about Gordianus is given by F. Kaltenbrunner, Die Vorgesichte der gregorianischen Kalenderreform, 113 (Vienna, 1876).

⁴Karoli Magni Capitulari, MGH. LL. II, 1, 60.

of holidays⁵ to computus. In all early catalogues of monastic libraries there are titles of works on this subject by the most famous writers, not only because it was necessary for them to keep track of the church festivals and saints' days, but also because astronomy was to them one of the most interesting subjects of the quadrivium.

A study of the most important medieval computi is valuable not only because they show us how the necessity and the desire for calendar reform gradually increased until it was carried through by Gregory XIII in 1582; but also because they show us the very slow but definite evolution of medieval astronomical ideas, since only those computists who knew astronomy could work out a true calendar.

The main problem in all computi, no matter how elementary, was the determination of the dates of Easter and the other movable feasts of the church. Although the methods of reckoning varied in the different countries, in each of them the date of Easter Sunday was calculated in its relation to that of the vernal equinox which, therefore, had first to be determined. Originally the time of the vernal equinox was considered to be on the twenty-fifth of March but, gradually retrograding, it at last appeared on the twenty-first, thus causing another problem for the calculators. It was not only necessary to find this latter date, but also that of the new moon in order to follow the rules for determining Easter Sunday, for according to most peoples Easter should come on or next after the fourteenth day of the moon (XIV lunae) in the month of the spring equinox. The earliest ecclesiastical calendars were founded upon two erroneous suppositions, one that the year has exactly 365 $\frac{1}{4}$ days; and the other, that 19 solar years contain 235 lunations. Because of these two errors the days of the vernal equinox and the days of the new moon gradually came earlier than they had in 325 A.D. at the time of the Council of Nicaea.⁶ Thus it was the duty of the computists to reconcile the lunar calendar of the Babylonians and the solar calendar of the Romans, and this they tried to do by many curious and inaccurate devices. Realizing that they could not make a lunar and a solar year coincide

⁵C. Wordsworth, The Ancient Calendar of the University of Oxford (Oxford, 1904), pp. 32-33.

⁶Most authorities say that the council of Nicaea (325 A.D.) fixed the method of determining Easter, but F.K. Ginzel, Handbuch der mathematischen und technischen Chronologie (Leipzig, 1914), III, 248, shows that this idea was started by Dionysius Exiguus in order to secure greater prestige for his Canon paschalis (525 A.D.).

exactly, they tried to make cycles of solar years. But the calculations for these cycles depended upon the methods of patristic "authorities," and not until the time of Grosseteste, upon observation, and were therefore more or less inaccurate. The desire to solve these problems gradually led to a more thorough study of the astronomical theories necessary for making calendars.

The Computus of Robert Grosseteste has been selected for translation because for sundry reasons it is one of the most important and thought provoking treatises on the subject written prior to the sixteenth century. The only other computus with which it can be compared is that of Roger Bacon,⁷ the student and friend of Grosseteste; but Bacon's work contains a great deal of irrelevant material and does not add enough new ideas to make its translation more worthwhile than that of Grosseteste. The bishop was an austere and serious-minded person and in his treatise no time or space is wasted in the diverting, but needless explanations and far-fetched illustrations, so often found in other works of a similar nature. Grosseteste, unlike Bacon, does not stop to search the pages of the Etymologiae of Isidore of Seville (c.570-563) for curious derivations for the terms he wishes to use; but states his theories and arguments in as brief a manner as possible, evidently presupposing a general knowledge of the subject on the part of his readers. Considering the vast number of computi written between the second and thirteenth centuries, it is not surprising that Grosseteste felt that he really did not need to explain his words. The style of this computus shows that the bishop had a truly scientific attitude of mind and was not merely an antiquarian; although it must be admitted that some of his ideas are not as scientific as his method. He states the astronomical theories of his different authorities, contrasting and comparing them; ending the discussion of each as he does that of Ptolemy, with a statement rather unusual for his time, "and thus our calendar would be corrected if the length of the year that Ptolemy reckoned is correct,"⁸ showing that he dares to disagree even with this favorite authority. After giving these opinions, he then presents his own solutions which in a number of instances were later proved to be correct. Not only is Grosseteste's style more scientific than that of some of his contemporaries, but he actually advocates working out the problems of time reckoning by experimentation and with astronomical instruments, and not simply by tables and cycles. He may justly be given the credit for being

⁷For information concerning the authenticity of Bacon's work see R. Steele, op. cit., XXI-XXII.

⁸Chapter I.

one of the very first writers in the Latin West to do this to any great extent.

Modern historians have usually neglected the part played by Grosseteste in the intellectual development of his period, because the fame of the student has tended to eclipse that of the master, although Bacon himself and his contemporaries continually praised Grosseteste and acknowledged their indebtedness to him. He was the center of the group of those who were beginning to break away from the old system of reliance upon authority and to check their propositions by reason and experimentation. Bacon frequently says that it was from Grosseteste and Adam Marsh⁹ that he received his first ideas of the experimental method. In the various works which Bacon wrote on the subject of calendar reform¹⁰ he cites Grosseteste as his chief authority, and certain important new theories for the reform are identical in the computus of each. Both say that in order to correct the chief error in the method of determining Easter day one must base his reckoning on the actual astronomical length of the solar year, not on lunar-solar cycles. Also that astronomical instruments or newly verified tables should be used to determine this length, after which it would be possible to calculate correctly the true date of the vernal equinox and the day of the first full moon after the equinox, which was to be used as the paschal limit (terminus paschalis) from which Easter Sunday could be found.

In later computi the treatise of Grosseteste is more frequently mentioned than those of his contemporaries. This may be due in part to the fact that Grosseteste was one of the most outstanding churchmen of the thirteenth century, but is also due to the fact that there were many suggestions in his computus which were valuable as a basis for further projects of calendar reform. The treatise which shows most clearly the influence of Grosseteste upon later writers, is that of Cardinal Pierre d'Ailly¹¹ (1350-

⁹One of Grosseteste's best friends, and one of Bacon's teachers at Oxford, infra, p. 21.

¹⁰Roger Bacon, Opus maius, ed. of J.H. Bridges, I, 276 ff., 1897-1900; Opus tertium, ed. of J.S. Brewer, in Opera quaedam hactenus inedita (London, 1859), I, 1. Computus, Steele, op. cit. For the influence of Grosseteste on Bacon, see especially, A.G. Little, Roger Bacon Essays (Oxford, 1914), and H. Felder, Geschichte der wissenschaftlichen Studien, in Franziskanerorden bis um die Mitte des 13. Jahrhunderts, Freiburg i.B., 1904.

¹¹Petrus de Alliaco--exhortatio ad concilium generale Constantiense super correctione calendarii, in J.D. Mansi, Sacrorum conciliorum Nova (Venice, 1785), XXVIII, cols. 370-381. Grosse-

c.1420) which he presented to the Council of Rome in 1412 and to the Council of Constance in 1417. It is comparatively short and merely summarizes the three principal errors in the current system, and the method of correcting them; (1) the length of the year had been incorrectly determined, (2) the equinoxes and solstices and immovable festivals of the Holy Church do not come at the right time because the length of the solar year is incorrect, therefore after every 134 years they would come one day too soon, (3) the placing of the Golden Number in the cycle of nineteen years is incorrect; therefore after 200 years, according to the calendar, the moon is only one day old when in reality it is three or four. After having quoted from Bede, Pliny, Ptolemy and others to show that these mistakes were not corrected in their works, he then gives three methods for remedying these errors, quoting in each case directly from the compotus of Grosseteste.

The chief value of Grosseteste's treatise lies in the fact that it was the first one in which the Arabic sources were used to any great extent; he was the first to discard the ecclesiastical system of concurrensts, regulars and epacts in favor of the Greek and Arabic astronomical theories. In this connection it is interesting to contrast the work of Grosseteste with that of his well-known contemporary, Johannes Sacro Bosco¹² (d. 1244-1256?), who although he wrote a compotus at approximately the same time, showed only a limited knowledge of Arabic theories. From these Arabic sources Grosseteste got many of his principles and new methods of calculation; however he does not adopt them unless he thinks they are correct. In this he is much superior to many of his successors who accepted without question Arabic astronomical principles.

Although the compotus of Robert Grosseteste has been the one used for translation, many extracts will be taken from that of Bacon, (the former being primarily a scientific treatment of the subject, and the latter an historical one) as well as from other contemporaries of Grosseteste, for the purpose of explaining more fully the subject of calendar reform in the thirteenth century.

teste's Compotus was mentioned at other councils by Cardinal Cambrai, Nicholas Trivet, and others.

¹²Infra, pp.22-23.

II. THE ECCLESIASTICAL SYSTEM OF TIME RECKONING

In looking over catalogues of medieval manuscripts, one is astonished at the great number of compoti which were written between the fourth and sixteenth centuries. Almost every writer who was at all interested in scientific subjects, seems to have at least one to his credit. But after examining the ecclesiastical method of reckoning time, one is no longer surprised. A system so confused and illogical was in continual need of correction and readjustment. In order to understand just what these difficulties were and why they were hard to remedy, it will be necessary to explain the derivation of this system from the much less complicated lunar, solar and stellar calendars of earlier peoples.

The Babylonians, mainly on account of their clear and starry nights, had first worked out a scheme of lunar divisions of time; whereas the Egyptians had chosen the sun as their chronometer, the sun being one of their chief gods. But for agricultural purposes a year was too long a unit of time, so the Greek peasants, not being able to calculate seasons by a phenomenon such as the overflowing of the Nile, began as early as the period of Hesiod to regulate their calendars by the movements of the stars. Even in late Roman times this same stellar system was in use.

Although agriculture was one of the most important incentives for establishing regular intervals of time, religious needs must also be taken into account. So periods shorter than seasonal ones had to be made because all lucky and unlucky days, all festivals and holy seasons should be noted, as Bacon says (quoting from Ecclesiastics, III, 1) in the opening sentence of the Compotus, "omnis tempus habent et suis spatiis transeunt universe sub sole, ut Saloman testatur."¹

After the founding of Rome still another calendar was gradually worked out, a civil one for purposes of business and government. The early Romans sometimes determined the length of the year according to the movements of the sun and sometimes according to those of the moon; for instance the calendar attributed to Romulus was probably solar and that to Numa,² lunar. However by

¹Bacon, op. cit., p. 1.

²Although as early as the time of Cicero, various writers recognized that it was merely a legend, the idea that Numa had been the first to divide the year into twelve months with 355 days, remained throughout the Middle Ages. For instance in the

509 B.C., the solar one had come into general use and from then on the Romans tended to ignore the moon as a means of marking divisions of time.

The average number of days in a Roman year was $366\frac{1}{4}$, but their calendar was arranged by cycles, and not by single years. By the intercalation of extra days in certain years, the civil calendar was made to coincide with the seasonal one, but for various reasons these extra days were not inserted during the years 64-59 B.C., therefore religious days reckoned according to the civil calendar finally did not come in the proper season. So in 46 B.C., under the direction of Julius Caesar, a new calendar was adopted with a solar year of $365\frac{1}{4}$ days, the extra fourths being taken care of by the insertion of an intercalary day (dies bissextilis) in the fourth year in the month of February. The instruction to place this day in the fourth year was expressed in the phrase quarto quoque anno which, due to the ancient system of reckoning inclusively, was interpreted to mean that an intercalary day was to be inserted every third, instead of every fourth year. Thus at the end of each period of thirty-six years, there would be three extra days, so the Romans were not much better off than they had been before. In this solar calendar of Caesar no attempt was made to co-ordinate the lunar and solar systems, the months being used only as a rough division of time.

The ecclesiastical calendar adopted by the primitive Christians³ was founded in part upon Caesar's system, their basic unit the year, also being solar. But instead of placing the most important festivals (especially Easter) on fixed dates, they arranged them as movable feasts and calculated their dates in relation to that of the vernal new moon. Thus unfortunately the moon was restored to its place in time reckoning, and the determination of the exact day when the moon was really "new" became the chief problem of all computists up to 1582. They could have regulated their festival dates rather easily by the sun's motion alone, but when they tried to reconcile solar and lunar periods, and to make the subdivisions of the year depend upon the phases of the moon,

historical introduction to his Compotus, Gordianus says "Primus tamen Romulus Romam civitatis fondator, annum solarem per 10 menses distinxit--Deinde Numa Pompilius duos predictis mensibus ap-suit." Also this sentence is in the Anon. Massa Compoti, Vespasian 4 II.

³The best discussion of early Christian Easter Tables and Compoti is given by E. Schwartz, "Christliche und jüdische Ostertafeln," in Abhand. d. Königl. Gesellschaft d. Wissens. zu Göttingen, phil.-hist. Kl. N. Folge, VIII, nr. 6 (Berlin, 1905).

it was very difficult to make the astronomical, civil, and ecclesiastical calendars coincide. The Church also had the impossible task of trying to co-ordinate three periods of time which had no common measure; the week, the lunar month, and the solar year!

Because Christ was crucified about the time of the Jewish Passover, and because the early Christians very naturally adopted some of the religious practices of the Jews, the date of Easter was at first closely connected with that of the Passover. This feast was celebrated on the fourteenth day of the moon in the first month (Nisan) of the Jewish ecclesiastical year, which was the month of the vernal equinox. Throughout the first century of the Christian era while they were still celebrating their festival on this date, the Christians had their Easter on the first Sunday after the day of the full moon. But later when the Jews, on account of inaccuracies in their cycles, began to celebrate the Passover before the vernal equinox only a small group of Christians, the Protopaschatians, followed their example. Other Christians, the Quartodecimans, then began to celebrate Easter on the very day of the fourteenth moon, even when that day was not a Sunday. Before long however, the majority of Gentiles objected to any connection between Easter and the Jewish festival, and each church began to decide for itself the dates of the new and full moons.

The only thing upon which most Christians now agreed was that Easter must come after the vernal equinox and on the Sunday which came on or after the fourteenth day of the moon. The Alexandrians said that it must be the one which did not come earlier than March 21st; the Romans that it might be the one which came earlier than that provided it did not come before the vernal equinox. The Alexandrian custom permitted it to be the fourteenth moon which came as late as April 18th; but the Romans said not later than April 17th. During the fourth century the date of the vernal equinox had been fixed on March 25th, but due to the precession of the equinox it gradually came at an earlier time by the end of each cycle. This was another cause of difference among Christian churches; for while some kept the fixed date, others changed the reckoning of the ecclesiastical calendar to coincide with the astronomical one.

As early as the beginning of the third century the makers of church calendars began to construct cycles in order to determine the date of Easter, cycles which would tell in advance for a period of years the dates of Easter, were called tabulae, cycli, and canones paschales. But as these cycles differed in the number of years before which Easter would again come on the same day of the year (because they reckoned the day of the new moon in various

ways, and the limits of Easter, and the relation of Easter to the fourteenth day of the moon), there was still not much chance for unity until they should adopt a common rule, which they made no attempt to do until the sixth century.

The calculators, not having instruments by which they could determine an astronomically true date for the vernal full moon, based their cycles upon the chief Greek one—that of Meton⁴ which had been corrected by Callippus. This was a period of nineteen years, called in the Middle Ages cyclus decemnovenalis, whose main purpose was to connect the lunar month and the solar year. According to Meton, after nineteen years the new moon dates again come on the same days of the year as in the first year of the cycle. In nineteen solar years there are 235 lunations, a number which being divided by nineteen gives twelve lunations for each year with seven as a remainder to be distributed among the years of the period. Therefore seven years of this cycle contain thirteen months each, these years being the third, fifth, eighth, eleventh, thirteenth, sixteenth, and nineteenth of the cycle. In order to preserve a more accurate correspondence between the civil month and the lunation, Meton divided the cycle into 125 months of thirty days each, and 110 months of twenty-nine days each. The number of days in the period was therefore 6940. However, the exact length of nineteen solar years is 19 times 365.2422 equals 6939.6018 days or 6939 days 14 hours, 26.592 minutes; therefore the Metonic period which was exactly 6940 days, exceeded nineteen revolutions of the moon by practically nine hours. On the other hand, the exact time of a synodic revolution of the moon is 29.5305 days; so that 235 lunations contain 235 times 29.5305 equals 6939.688 days, or 6939 days 16 hours 31 minutes, therefore the period exceeded 235 lunations by only seven hours.

About a century later Callippus,⁵ realizing that the Metonic cycle was not entirely accurate, attempted to correct it by establishing a cycle of seventy-six years (four periods of nineteen years) at the end of which he deducted one day. So that there were three Metonic periods of 6940 days each, and then one of 6939 in every cycle of seventy-six years. Now the error amounted to only one extra day in 304 years which could be corrected by again subtracting one day. This cycle of Callippus was the basis for the best ones of the Middle Ages, and was the one criticized by Grosse-teste when he worked out another method for finding the new moon days.⁶

⁴Meton (c. 432) Athenian astronomer. P. Duhem, Le système du monde (Paris, 1914), I, 108.

⁵Ginzell, op. cit., II, 409-19.

⁶Chapter IV.

In the Christian era, the first important constructor of an Easter table was the Greek mathematician Anatolius⁷ who was a teacher of Aristotelian philosophy in Alexandria until 269 A.D. when he became bishop of Laodicea, (which office he held until his death in 382). He wrote on various mathematical subjects and was the founder of the so-called Alexandrian cycle of four periods of nineteen years each. This cycle was based on that of Callippus and although not perfect, was the most practical one in the Middle Ages. It consisted of 27759 days which were equal to seventy-six Julian years; each period of nineteen years having twelve common lunar years and seven leap-years. In his introduction Anatolius stated that the vernal new moon of the first year of the cycle was to come on the twenty-second of March and the first day of the equinox on the nineteenth of that month. Also he said that Easter should come on the day of the full moon after the vernal equinox; which principle gradually became the accepted one in Alexandria, among the Eastern Roman writers, and before long spread to the West. The Quartodecimans and the Protopaschatians still differed from this rule, the former insisting that Easter be celebrated on the fourteenth day of the moon even if it did not fall on a Sunday, and the latter celebrating it according to the calculations of the Jews.

The fact that Easter did not come on the same day in every place was the cause of a good deal of anxiety among the bishops, and the subject was brought up at various councils. At the Council of Arles in 314 a decree was issued that Easter should be determined according to the method used in the "western churches, the church at Alexandria and most of the eastern churches."⁸ Later the Council of Nicaea asked the Protopaschatians to fall in line with the rest of the churches and not to reckon Easter according to the Jewish calendar. The Council of Nicaea did not give any definite rule for the determination of Easter but merely asked that there be unity in all the different localities, presumably according to the Alexandrian rule. The efforts of these and other councils were not wholly successful and the churches continued to make their own calculations.

Annianus,⁹ an Egyptian monk (412 A.D.), made a valuable

⁷His introduction is quoted by Eusebius, Historia ecclesiae, VII, 32, in Migne, Pat. graec., XX, 727. Anatolius says (incorrectly) that according to the Jews the Passover must come after the spring equinox, and this is the rule he adopts for the Easter cycle.

⁸Mansi, op. cit., V, 327.

⁹Eusebius gives an extract of this work in his Historia, VII, 32. Cf. Grosseteste, Chapter VIII.

improvement in the lunar cycle of nineteen years by combining it with the solar cycle of twenty-eight years, making a period of 532 years. The advantage of a cycle of 532 years was that at the end of that period the Easter full moon would again come not only on the same day of the month but also on the same day of the week on which it came in the first year of the cycle. Therefore Easter Sunday would also come on the same day in the 532nd year as it did in the first year of the cycle.

The last important table of the fifth century was the Cursus paschalis of Victor of Aquitaine¹⁰ written in 457 at the instigation of the archdeacon Hilarius (pope 461-468) who wished to know the causes of the differences between the Roman and Alexandrian systems. According to E. Schwartz, this was the last attempt of the West to make a cycle which did not depend entirely upon the Alexandrian one. Victor showed his real intelligence by ignoring the period of eighty-four years, that other Latin computists had been trying to improve, and used a cycle of nineteen years, which was somewhat different from the Alexandrian one. He first gave a list of 532 Easter dates, at the end of which time the fourteenth moon would again come on the same day of the month and the same day of the week, because this period of 532 years is equal to twenty-eight lunar cycles of nineteen years or nineteen solar cycles of 280 years. According to his table the limits of Easter were March 20th and April 16th.¹¹

The cycle of Dionysius Exiguus,¹² constructed about 525, proved to be much more popular and useful than that of Victor. Dionysius based his calculations on the Alexandrian cycle of nineteen years. In order to give his system more prestige he said that the Council of Nicaea had instructed the bishops to use the cycle of nineteen years, and also that they had said that the Easter full moon could not come before March 21st or later than April 18th, and that Easter should be celebrated between the fourteenth and eighteenth days of the vernal moon.¹³ He made an Easter

¹⁰M. Cantor, Geschichte der Mathematik, 3d edition, I, 531, 1914. F.K. Ginzel, op. cit., III, 245-47. Victrii calculus ex codice Vaticano editus a G. Friedlein. in Bull. di bibliogr. e di storia d. sci. mat. IV (Rome, 1871), 443-63. Mansi, Collect. IX. col. 113.

¹¹Although this Cursus paschalis was dedicated to Leo I, it did not become the official Roman system. However, it must have spread rapidly as it was criticized in Italy by Cassiodorus in 519, and was used by Victor of Capua in his Chronicle in 550.

¹²Ginzel, op. cit., III, 247-51, Migne, Pat. lat. LXVII. R.L. Poole, "The Earliest Use of the Easter Cycle of Dionysius," in English Historical Review, XXXIII (1918), 62.

¹³Ginzel, op. cit., III, 248.

table of ninety-five years which he said was based on that of St. Cyril, and on the so-called decree of the Nicaean council. For us the most important innovation in this treatise was his system of dating from the year of the Incarnation.

The more or less general adoption of the Dionysian cycle¹⁴ at last brought about some semblance of uniformity in the method of reckoning Easter in the Latin West. The twenty-first of March was now considered to be the date of the spring equinox and the Easter full moon was calculated according to the Alexandrian cycle of nineteen years. By this rule 235 synodical months equal nineteen tropical years. A tropical year had 365 days and five hours. However nineteen tropical years equal 6939.75 days while 235 lunar months equal 6939.6885 days, causing an error of one hour and twenty-eight minutes by the end of nineteen years, which would amount to one day in every 310 years. Also a tropical year was eleven minutes and fourteen seconds shorter than the 365 days and six hours which the computists calculated, which would make it necessary to subtract one day in every 128 years. But as this was not perceived by them, in every 128 years the spring equinox came earlier by one day. The correction of the errors in these cycles is Grosseteste's main object in the Computus, because only by means of accurate cycles can Easter and the other movable feasts be determined.

¹⁴This cycle was known to a number of writers soon after 525 (for instance, Cassiodorus recommended that it be studied) but neither he nor any one else seems to have used it immediately.

III. SOME EARLY MEDIEVAL COMPOTISTS¹

Grosseteste mentions only one European compotist, Rabanus Maurus,² but it is evident from his work itself that many of the curious facts concerning such non-astronomical ideas as "hours of the planets," "minutes of a day," and "climates," as well as many of his medieval methods of constructing calendars, came from earlier compotists and astronomers. Due to their ignorance of astronomy, the early medieval compotists were not able to construct a system of reckoning time which would be accurate, but had to make cycles of lunations, regulars, epacts, and concurrents, to aid them in arranging their tables of Church festivals. Very gradually the Greek and Arabic ideas of astronomy spread among the western European writers until by the time of Grosseteste and Bacon, the compotists were wise enough to see some of the errors in the ecclesiastical calendar.

Boethius³ had tried in vain to make the study of Greek astronomy and mathematics popular among the Goths, but he had not even been able to carry out his plan of translating all the astronomical works of Aristotle and Plato and the geometry of Euclid. Cassiodorus⁴ had entertained a similar idea but in his works there is only one short chapter, in the Institutiones saecularium lectionum, which contains any astronomical material. He merely gives a definition of astronomy and the seven climates,⁵ taking most of his facts from the writings of Ptolemy.

One of the most popular "authorities" of the early compotists was Isidore of Seville. In the third book of his Etymologiae⁶ he discusses mathematics, astronomy and the calendar, as

¹Only the compotists and encyclopedists from whose works Grosseteste drew any material for his Compotus, are included in this chapter.

²Infra, p.15.

³Born in Rome about 480, put to death by order of Theodoric in 524. Sarton, Introduction to the History of Science (Baltimore, 1927), I, 424-26

⁴Was born about 490 and died in 580. His Institutiones is printed in Migne, Pat. lat. LXX, cols. 1105-20.

⁵For an excellent discussion of the history of the seven climates see E. Honigsmann, Die sieben Klimate (Heidelberg, 1929). He says that Cassiodorus was the first one in the West to discuss these "climates."

⁶Migne, Pat. lat., vols. LXXXI-IV. Sarton, op. cit., I, 471-2.

well as medicine and law, and his De natura rerum deals exclusively with astronomical subjects. For much of his material he depended upon Aristotle (at second hand), St. Clement, St. Augustine, Hyginus, and Suetonius. It is true that he mentions Ptolemy but knew him only through the work of Cassiodorus; also Pliny and Chalcidius but only through St. Augustine. On the whole very little helpful information could be gained from his books, since his theories were based on the erroneous ideas of the Fathers; and he knew even less astronomy than St. Augustine. The computists who depended upon the works of these three writers naturally could not frame well-constructed calendars. However, Bacon and many others never failed to borrow many facts from the pages of Isidore.

The English compoti, even so early as the eighth century, were on the whole much better than those which were written on the continent. The first English treatise on the calendar, which was of any value, was the De temporum ratione⁷ of Bede. The fact that he used personal observation to check some of his theories made his work a real contribution to knowledge, and kept it from being a mere compilation of earlier material. Due to the book-collecting zeal of Benedict Biscop and the monks who followed him, the twin monasteries of Wearmouth and Jarrow were rich in books so Bede was able to have at least some of the works of Pliny, who had used many Greek and Roman sources. Thus the scientific knowledge displayed in the De temporibus (c.703 A.D.), and the De tempore ratione (725 A.D.) is much better than that of Isidore. The chief sources of the De tempore ratione besides Pliny, are Isidore, Macrobius,⁸ Victor of Aquitaine, Victor of Capua and Dionysius Exiguus. Bede was one of the first writers to recognize that the apparent ages of the new and full moon and their ages according to the Easter cycles were not in accordance;⁹ that the moon appeared to be three days older than it was in the ecclesiastical calendar. He gives the various theories concerning the proper date of Easter and the dates of the equinox, sometimes trying to reconcile them, and sometimes merely stating both sides of the

⁷Opera omnia, vol. VI, J.A. Giles (London, 1843-44). M. Manitius, Lateinische Literatur des Mittelalters, I, 70-87. Duhem, Le système du monde, III, 16-20.

⁸His De nuptiis philologiae et Mercurii et de septem artibus liberalibus libri novem was one of the favorite sources of medieval computists. Book VIII, on astronomy, had an explanation of the semi-heliocentric system. Sarton, op. cit., I, 385.

⁹However, the first work to give a clear discussion of this difference, was the Computus of Master Conrad, c.1200. Cf. F. Kaltenbrunner, op. cit., p. 120.

question. In spite of its obvious inaccuracies, his work remained the most authoritative one up to the time of Grosseteste. The computists who followed him were seldom as good, and only a few were better. Although Grosseteste does not cite his works some of his ideas are obviously taken from the writings of Bede, and Bacon has several references to him.

Alcuin¹⁰ helped to spread abroad the works of Bede, but produced no worthwhile treatise on the calendar. He had been educated at York under Egbert, the favorite student of Bede, and his successor Albert, who brought many books to the monastery library. In this school the monks were encouraged to study secular as well as religious subjects, mathematics and astronomy being particularly popular. When Alcuin went over to the palace school of Charlemagne he was encouraged by the latter to continue the study of mathematics, especially in its relation to astronomy, a subject in which Charlemagne was keenly interested. More than once in the midst of a campaign the emperor noticed that the moon was apparently not as old as it was according to the tables so he wrote immediately to Alcuin asking for an explanation. There are a number of Alcuin's letters,¹¹ particularly during the period from 797 to 799, which give answers to some of these questions of Charlemagne.¹² In letter 126 he said that the saltus lunae should come on the last day of November in 797, because that was the last year of the nineteen year cycle of Dionysius. He also wrote a treatise on the whole subject of the saltus lunae which he sent to the king, with a warning that there were some who were trying to do away with the Roman custom of calculating the saltus.

Beginning with Rabanus Maurus,¹³ a student of Alcuin, the computists are more ignorant than ever, in fact none of them before the writers of the eleventh century, know any astronomy whatsoever. Rabanus was born at Mainz in 776 and studied first at Fulda and then with Alcuin at St. Martin of Tours. In 822 he became abbot of the monastery of Fulda, and in 847 archbishop of Mainz, where he died in 856. He wrote his computus about 810, using principally the works of Isidore and St. Cyril of Alexander.

¹⁰C. J. B. Gaskoin, Alcuin, His Life and Work (Cambridge, 1904). Specht, Geschichte des Unterrichtswesens in Deutschland, 86-149. Sarton, op. cit., I, 528.

¹¹Letters in Jaffé, Monumenta Alcuiniana (Berlin, 1873), VI.

¹²F. Piper, Karls des Grossen Kalendarium und Ostertafel, Berlin, 1858. Annales Laurissenses et Einhardi, in MGH. SS. I, 171 (under the year 786).

¹³Duhem, op. cit., II, 20ff. M. Manitius, op. cit., I, 288-302; II, 802. Sarton, op. cit., I, 555.

and mentions Pliny only once. Rabanus was much more conservative than Alcuin and his work shows that he must have had a strong distaste for original enquiry, since he accepts the earlier cycles without question and does not recognize even the most outstanding errors. Rabanus is the one medieval compotist whom Grosseteste mentions by name, though only to refute him.

Next to Bede, the two compotists most frequently quoted by medieval writers were Helpericus¹⁴ and Gerland,¹⁵ in fact in all of the compoti which include a chapter dealing with the history of this subject, these three are always grouped together. Helpericus lived in a monastery in Auxerre where he was a teacher of grammar and mathematics. His compotus was written at the request of his students, and he himself said that his work was unoriginal and based almost entirely upon the treatise of Bede. However, it became one of the most popular text-books on the subject. It was written about the middle of the ninth century and is of the usual type, dealing with the cycles of epacts, lunar and solar regulars, and the names of the months, and brief discussions of the length of the year, the leap-year, and the movement of the sun around the zodiac. His most important contributions are his statements that in order to find the proper day for Easter it is necessary to observe the equinoxes and solstices; and that the epacts are incorrect in the eighth, eleventh, and nineteenth years of the cycle of nineteen years. His Compotus was used by Arnulf of Avignon in his chronicle (1026), by Gerland, and Notker the German (950-1022), a monk at St. Gall, in their compoti.

Practically nothing is known about the life of Gerland, except that most of the later compotists say that he was born "in confine Germanie,"¹⁶ probably near Besancon or in upper Lotharingia. He wrote on the abacus and on the reform of the calendar, his compotus being based in large part on that of Bede; as he himself says in the opening sentence, "Sepe volumina domini Bede de scientia computandi replicans."¹⁷ A Tabula cycli solaris, i.e. a perpetual calendar for finding Easter dates, is also ascribed to him. He was in frequent correspondence with the mathematicians

¹⁴Helpericus says that Lupus of Ferrière and Haino were his teachers. Manitius, op. cit., I, 446. Duhem, op. cit., II, 71-76, 1925.

¹⁵In catalogues of manuscripts his name is often written Garland, or Garlandi, but he must not be confused with John of Garland, who may also have written a compotus, but not the one entitled Compotus Gerlandi imitantis Bedam.

¹⁶Gordianus, f 2. Compotus, Ms. Vindob. 5239.

¹⁷Compotus, Vespasian A IX, 2 fol. 1.

of Lotharingia and from his works we may judge that he was a much better astronomer than most of his predecessors, being one of the first sensible critics of the Dionysian system. According to him Dionysius began his cycle of 532 years seven years too late, a criticism that was usually accepted by all computists until 1582.

Another important critic of the Dionysian cycle was Marianus Scotus,¹⁸ a contemporary of Gerland. He was born in 1028, and later became a monk at Fulda and finally abbot. In the introduction to his Chronicle, written in 1076 A.D., he says that the Nativity was in 22 B.C. in the Dionysian calendar, and the Crucifixion in 13 A.D. His introduction was abridged and commented on by Robert of Lotharingia. Marianus also wrote a computus and short treatise De magno ciclo paschali.

¹⁸Migne, Pat. Lat. CXLVII, cols. 601-802. Manitius, op. cit., II, 388-94.

IV. SCIENCE IN OXFORD BEFORE THE TIME OF ROGER BACON

Thus new compoti were being written year after year but very few were any better than those which preceded them. However there is a marked improvement in the English compoti of the thirteenth century, especially those written in or near Oxford, due primarily to the fact that in the eleventh, twelfth, and early part of the thirteenth centuries, scientific knowledge in Oxford was superior to that in either France or Germany. One important reason for this was the Arabic learning which was introduced into England at a very early date. From the eleventh century on, the English became more and more interested in Arabic science which was accepted there earlier than in the majority of western countries, for instance in France, where the university inveighed against this new learning even as late as 1235.¹

England gained her knowledge of Arabic science first by way of Lotharingia² and then from Spain.³ From the time of Cnut on through the reign of Henry III many Lotharingian bishops and teachers had been called to England by kings and nobles, and through these men the English obtained their first hint of Arabic science, the knowledge of the astrolabe. These Lotharingians were well educated, in secular as well as religious subjects, and in a number of cases they were called to England primarily on account of their learning. It was Robert of Hereford,⁴ invited over by William the Conqueror, who first brought over the Chronicon of Marianus Scotus. Robert was, for his day, a distinguished mathematician, and that he was skilled in the use of the abacus may be learned from his epitaph by Godfrey, prior of Winchester.

One of the first important men of science in the vicinity of Oxford was Robert Cricklade,⁵ prior of St. Frideswide. He was born probably in Cricklade in the first half of the twelfth century where he received the first rudiments of his education; later

¹H. Rashdall, History of Universities, II, 136.

²J.W. Thompson, "Introduction of Arabic Science into Lorraine," Isis, XII (1929), 184-94. C.H. Haskins, Studies in the History of Medieval Science, pp. 333ff.

³Haskins, op. cit., p. 340.

⁴Haskins, op. cit., pp. 334ff. G. Hardy, Descriptive Catalogue, II, 291. Oxford Collectanea, II, 160-65.

⁵Haskins, op. cit., p. 169. Sarton, op. cit., II, 426-27. Dugdale, Monasticon, VI, 135. Burrows, Collectanea, 2d ser., II, 161.

he studied in the schools of Oxford. Giraldus Cambrensis mentions having seen him as an old man when he himself was young; he speaks of him as a "vir litteratus et in scripturis eruditus et Hebraice quoque linguae non ignarus."⁶ In his early years Robert was interested in scientific subjects and made an abridgment of Pliny's Natural history for his students, and a number of copies of this work were soon made in the schools and libraries in and near Oxford. Most of his teaching was done before 1141 when he became prior of St. Frideswide, but he continued to have a great deal of influence over students in Oxford until his death in 1180. Late in his life Robert made a trip to Italy and Sicily (c.1158), and although no mention is made in any of the sources on Cricklade that he took back any book to England, it is highly probable that he did.

Other teachers soon found their way to Oxford and helped make that city famous for its schools even before the founding of the university. Practically all of them studied secular subjects as well as theology; and all of them were friends of Grosseteste. Among the scientists were Edmund Rich of Abindon,⁷ later archbishop of Canterbury, writing on grammar, logic and the sciences of the Quadrivium; Daniel of Morley⁸ who had such a keen interest in mathematical subjects that he finally went to Toledo because he could not find what he wanted in Oxford or Paris; and Richard Fitzacre,⁹ Robert Bacon,¹⁰ and William of Leicester.¹¹

From the writings of Grosseteste and Roger Bacon it is evident that many were also interested in languages; for instance Nicholas the Greek¹² who helped Grosseteste with some of his translations; John of Basingstoke¹³ who translated a Greek grammar; and an unknown "homo sapientissimus" whom Bacon mentions as having worked on a new version of the Vulgate for thirty or forty years. Both Grosseteste and Bacon said that languages should be studied not only for themselves but principally for their use in the study of science—in order that the scientist might read earlier authorities on his work, and to be able to make new words

⁶Opera omnia, ed. by Brewer, VIII, 65.

⁷D.W. Wallace, St. Edmund of Canterbury, (1893) Surius, De probatis sanctorum Historiis, VI, (1575).

⁸Haskins, op. cit., pp. 126-28. Sarton, II, 385.

⁹Haskins, op. cit., p. 132.

¹⁰"Epistolae," Adam Marsh to Grosseteste, Brewer, in Monumenta franciscana, I, 342, 1858.

¹¹Hardy, Descriptive Catalogue, II, 56.

¹²Sarton, op. cit., II, 584.

¹³H. Suter, Die Mathematik auf den Universitäten des mittelalters, 84. (Zürich, 1887)

with which to describe the method and results of the experiments. Although it is very probable that neither Grosseteste nor Bacon knew Arabic they used Arabic science, and the Greek science which they got by way of the Arabs.

Thus Oxford was a center in which it was natural that an advance in scientific subjects would be made; there were learned men who desired to know as much as possible, and plenty of opportunities for study. The greatest leader in this movement was Robert Grosseteste, who was constantly urging his students to study the sciences and languages.

Grosseteste¹⁴ was born in Stradbroke in Suffolk about 1175. We know very little concerning his early education but he probably studied first in the schools of Stradbroke. He must have gone to Oxford a few years before 1199 because Giraldus Cambrensis, in a letter to William de Vere speaks of him as a magister of arts at that time. In this letter Giraldus is recommending him to de Vere but as the latter died in this same year, Grosseteste was not under his protection for more than a few months. It is uncertain just what he was doing after 1199, but he may have gone to Paris to study, although the evidence for this is slight. About 1214 he became a chancellor or magister scholarum at Oxford where he remained until he became bishop of Lincoln in 1235. Most of his scientific treatises must have been written during his years at Oxford, since he was extremely busy with ecclesiastical affairs after 1235.

His first important astronomical work was probably the Compendium sphaerae,¹⁵ which was in part a commentary of the De sphaerae of Sacro Bosco. That this work was written early in Grosseteste's career is evident from the fact that in it he accepted without question the theory of epicycles and eccentrics which he criticises later on. It is interesting to note that he discusses the theory of the eighth sphere of Thābit ibn Qurra which had just reached England.

Grosseteste's Computus must have been written between 1230

¹⁴ F.G. Stevenson, Robert Grosseteste (London, 1889). H.R. Luard, Preface to the Letters of Grosseteste (London, 1863). J. Felten, Robert Grosseteste (Freiburg, 1887). Perry, Life and Times of Bishop Grosseteste (London, 1871). S. Pegge, The Life of Robert Grosseteste (London, 1793). Chronicon de Lanercost, ed. Stevenson, pp. 43-46. Letters of Adam Marsh, ed. by Brewer, Monumenta Franciscana (London, 1858).

¹⁵ L. Bauer, Die philosophischen Werke des Grosseteste (Munster, 1912).

and 1232, because in some of the earliest copies of this treatise the table of Arabic and Christian years begins with 1230 and 1231. Also he himself says that the De sphaera of al-Bitruji "has just lately come"; and he now questions the theory of epicycles and eccentrics, using the arguments of al-Bitruji. The latter's De sphaera had been translated in 1217 by Michael Scot¹⁶ who was in England by 1224 and thus it is very likely that it was through Scot's translation that Grosseteste got these theories. It was from this treatise that Grosseteste obtained his knowledge of Aristotle's homocentric spheres because he claims that Aristotle said there were nine spheres, whereas he accounted for only eight.

Another Oxford scholar of this period interested in mathematics and science was Grosseteste's closest friend, Adam Marsh.¹⁷ He was born in the diocese of Bath about the end of the twelfth century and was educated at Oxford under the direction of Grosseteste. He joined the Franciscan Order and about 1228 may have gone with another member of the order to Vercelli to study under the abbot of St. Andrew's. Adam Marsh spent practically all of his life in Oxford where he looked after the welfare of both students and masters. From Bacon's comments we know that Marsh did all he could to help Grosseteste further the progress of scientific studies and experimentation.

A rather mysterious John of London¹⁸ must have been a contemporary of Grosseteste and Adam Marsh, and he, like some of his successors, was a teacher of scientific subjects. John of Garland says of him,

"Effectus laicus fuit hoc in tempore doctor
Oxonise, biguit sensibus ipse tamen.
Omni litterula privatus, scivit et ivit
Ut laicos, servo vir Plato, mane rudis.
Hic de Londoniis fuerat, dictusque Johannes,
Philosophos juveni legerat ante mihi."¹⁹

Bacon mentions him twice and speaks of his knowledge and love of science.

By comparing the state of science in Oxford and Paris, it is easy to see that the former university was in advance of the

¹⁶Haskins, op. cit., p. 277.

¹⁷Roger Bacon, Opus Tertium, p. 187. Letters in J.S. Brewer, Monumenta franciscana, I, 77-489, 1858. Sarton, op. cit., II, 583. Denifle, Die Universitäten des mittelalters, I, 290.

¹⁸For a summary of all that is yet known about this Oxford teacher of science, see L.J. Paetow, Morale Scholarium of John of Garland (Berkeley, 1927), pp. 83-84.

¹⁹Paetow, op. cit., p. 83, note 15.

latter. It is true that William of Auvergne²⁰ (d.1249) had already become acquainted with the translation of the al-Bitrūjī's work, and Scot's translations of the writings of Aristotle, but his De universo shows that he very imperfectly understood their theories, and that he rejected all Greek and Arabic ideas which were contrary to the Christian doctrine. Throughout his Computus Grosseteste clearly states that the ecclesiastical calendar can be corrected by the adoption of Arabic and Greek principles of astronomy. Even as late as 1248-1256 when Bacon was in Paris the knowledge of astronomy was still very poor in that university, and the Oxford students and masters who went there later in their careers were not able to add anything to their scientific knowledge after they left Oxford.

The best known computist who first studied at Oxford and then went to Paris, was Joannes Sacro Bosco.²¹ Considering that his works were so popular for several centuries after his death, it is surprising that very little is known about his life. He was born probably in Holywood (Halifax) in Yorkshire, and has been variously designated as an Englishman, an Irishman, and a Scotchman. However all authorities agree that he studied at Oxford. Thus he must have belonged to that group of scholars skilled in philosophy, arithmetic, geometry, astronomy and kindred subjects, who studied there while Grosseteste was teaching. His De sphaera was written evidently while he was still in Oxford, for it was commented upon by Grosseteste in one of his earliest scientific works, also called De Sphaera. There are innumerable manuscript copies of Sacro Bosco's Sphaera, and it was frequently cited by contemporary and succeeding writers, showing that it was one of the most popular text-books in the later Middle Ages.

Sacro Bosco went over to Paris about 1230-33 to finish his studies and to teach letters and philosophy, and there he received his doctorate. He must have written his De anni ratione seu ut vocatur vulgo computus ecclesiastico in Paris, which although not as well-known in the Middle Ages as his Sphaera, is important in tracing the development of astronomical ideas in computi.

The exact date of the writing of this computus is hard to determine. According to the verses which are found at the end of some manuscript copies, the date of writing is given as 1244, a date which has also been given as that of his death, but from internal evidence it seems to have been written in 1232. In his

²⁰Sarton, op. cit., II, 588.

²¹Kaltenbrunner, Die Vorgeschichte der Gregorianischen Kalenderreform (Vienna, 1876). Duhem, op. cit. J.E. Sandys, History of Classical Scholarship (Cambridge, 1906).

discussion of the dates of the equinoxes and solstices, and later in that of the Golden Number, he uses 1232 "the number of years which have passed since the birth of Christ," as the basis for his calculations. This date also seems more probable than that of 1244 in view of the fact that his main authorities are Bede, Ptolemy and Alfraganus, and he even condescends to quote from Eusebius. From the fact that he mentions only one Arabic source, and that Alfraganus, and only one Greek, Ptolemy, it would seem that this compotus was not written in Oxford even as early as 1232, nor in Paris as late as 1244, for even William of Auvergne cites more than one Arabic scientist. Therefore Sacro Bosco must have written it about 1232 when he had been a student in Paris for two or three years. He wrote a number of other scientific treatises, Iudicarios astronomicos, Armilaris utilitates, Algorismus, and Breviarius iuris. He died about 1256 (or 1244?) and was buried in Paris.

The compotus of Sacro Bosco is in the nature of a compendium of the various methods of time reckoning and is one of the best of those written before the assimilation of Arabic science changed the astronomical knowledge of the calculators. He says that one day should be dropped in every 288 years to correct the calendar if one continues to reckon $365\frac{1}{4}$ days in each year; this is practically the same reckoning as that made by Ptolemy. Sacro Bosco also discusses the incorrectness of the cycle of nineteen years, saying that according to Ptolemy this cycle had only 6939 days and $16\frac{2}{3}$ hours whereas nineteen solar years equal 6939 days and eighteen hours; therefore the new moon date retrograded $1\frac{1}{3}$ hours in every period of nineteen years. In correcting for the new moon date for his period Sacro Bosco bases his calculations on the statement of Eusebius that in the year of the birth of Christ it came on the 23rd of March. Throughout his compotus Sacro Bosco quotes verses for remembering the different rules, many of which he takes from Ovid, Lucan, Vergil and other classic poets; a number of these verses are also in the Compotus of Grosseteste.

This compotus of Sacro Bosco may be considered as the last important one written in the "old style," that is, without the use of Arabic and Greek astronomy, and that of Grosseteste as the first one in the "new style," with the use of Arabic and Greek astronomy.

V. AN ANALYSIS OF GROSSETESTE'S COMPOTUS

In the Compotus Grosseteste gives a number of hints concerning his physical and geometrical explanations of the movements of the sun, moon, and planets, leaving the discussion of meteorological ideas concerning the nature of the earth and the heavenly bodies to the essays De sphaera, De motu supercaelestium, and De caelo.¹ In his Compotus he is interested primarily in obtaining accurate arithmetical calculations of their motions in order to make the proper adjustments in the calendar.

Grosseteste believed that the earth, a sphere, was the center of the universe and above it were the seven planets in the following order, Moon, Mercury, Venus, Sun, Mars, Jupiter, and Saturn,² then the eighth sphere of the fixed stars,³ and the primum mobile⁴ or ninth sphere. Like the Pythagoreans,⁵ Grosseteste believed that in the progression of the sun, moon and planets there were two movements about two different poles, one diurnal along the plane of the equator from east to west, the other annual, from west to east along the plane of the ecliptic. The sphere of the fixed stars moved from west to east, while the ninth sphere, moving more rapidly than any of the others, and imparting motion to all of them, revolved in the opposite direction.

Grosseteste seems to think this theory of homocentric spheres which makes it unnecessary to explain celestial movements by eccentrics⁶ and epicycles,⁷ is on the whole tenable but is not

¹Printed by L. Baur, in Die philosophischen Werke des Grossetestes, pp. 89-101.

²Cf. Grosseteste's diagram in Baur, op. cit., p. 11.

³I.e. the sphere of the constellations.

⁴Added by the Arabs to the eight spheres of Aristotle.

⁵Also from this school came the theory of concentric spheres; and two of Pythagoras' followers, Hicetas and Ecphantus were the first to place the earth in the center of the universe, J.L.E. Dreyer, Planetary Systems, ch. II. Cambridge, 1906.

⁶Movable eccentrics were used by the early Greeks to explain the irregular movements of the planets. The earth was the center of the universe and the sun and moon moved around it in concentric circles. But the centers of the planetary circles were on a line between the earth and the sun, the earth being outside of the small circles of Venus and Mercury but inside those of Mars, Jupiter and Saturn. As this system was useful only for

to be trusted because the "reckonings of the movements of the heavenly bodies according to Aristotle and al-Bitrūjī had not yet been checked by means of instruments."⁸ For two reasons, one scientific and the other historical, this is one of the most important assertions in his work; first it shows that he was not willing to accept anyone's statements, not even those of Aristotle, without checking them scientifically by means of instruments. In the second place it is another example of that age-long struggle between the followers of Aristotle and Ptolemy which started in the last period of Hellenic science. This argument was carried on by the Arabic scientists, witness al-Bitrūjī,⁹ and some of the medieval and Renaissance writers, until the Copernican system superseded both the Aristotelian and Ptolemaic theories. However, in Grosseteste's time it is only among writers who were philosophers as well as astronomers that we find those who refused to accept Ptolemy's ideas of eccentrics and epicycles.

Also for a very practical reason the theories of Aristotle and al-Bitrūjī cannot be used for the reform of the calendar, be-

the last three planets, it was soon superseded by one consisting only of epicycles, or a combination of eccentrics and epicycles.

⁷A system used to represent geometrically the variable velocities of the planets, and in the case of all the planets with the exception of the sun and moon, their stations, retrogradations and direct motions. Each planet moved around its epicycle (a small circle) whose center in the meantime was moving around the deferent at whose center was the earth. The sun and moon moved on their epicycles from east to west, the other five planets from west to east.

⁸Chapter I.

⁹al-Bitrūjī (Alpetragius), born near Cordova in the latter part of the twelfth century. He lived later in Seville and was the pupil of ibn Tūfāil, and developed his idea that the planetary system can be explained without eccentrics and epicycles, and with the homocentric spheres of Eudoxus. Each planet was attached to a sphere, all being moved by the primum mobile which was beyond those of the planets and of the eighth sphere. To the eighth sphere he gave two motions (trepidation of the equinoxes) one in longitude which is precession, and the other caused by the fact that the pole of the ecliptic describes a small circle around a mean position. The poles of the planets move in the same way, hence their inequalities in longitude and motion in latitude. This book, Theorica planetarum, was translated in 1217 by Michael Scot so had probably just reached Oxford when Grosseteste wrote his Computus.

cause "concerning the length of the year Aristotle has said nothing nor did Alpetragius say anything about the length of any year different from that which Ptolemy discovered."¹⁰

After this brief discussion of the nature of the movements of the earth, sun, moon, and planets, Grosseteste attacks the first problem in the reform of the calendar, the calculation of the length of the year.

As was mentioned above, there were two principal errors in finding Easter day by the system then in use in the western Church, (1) the determination of the length of the solar year was incorrect, and as a result, the date of the vernal equinox, and (2) the length of the lunar month was wrong, therefore the days of the new moons (most important of all, the vernal new moon) found according to the tables, did not correspond to those noted by observation. These errors made the co-ordination of the solar year and the lunar month more difficult than ever. According to the Julian calendar a tropical year equals 365 days and six hours, whereas the true length is 365 days six hours forty-eight minutes and forty-six seconds. As a result each year the vernal equinox came about eleven minutes and fourteen seconds earlier than it was supposed to according to the Julian calendar, which after 128 years would amount to one day. Also by modern calculations, nineteen tropical years equal 235 synodical months, and 235 of these months equal 6939 days, sixteen hours, thirty-one minutes, forty-eight seconds, but nineteen Julian tropical years equal 6939 days and eighteen hours. Therefore at the end of each cycle there would be a difference of one hour twenty-eight minutes twelve seconds and thus the new moon would come earlier each year by just this amount of time, which would equal about one day every 310 years. Thus it is easy to see why the medieval method of reckoning the fourteenth day of the vernal moon was incorrect.

Grosseteste says that the length of the Julian year had been based upon the calculation of Hipparchus¹¹ who had measured the revolution of the sun from one solstice back to the same solstice, or from one equinox back to the same equinox, and had said

¹⁰Chapter I.

¹¹He was born in Nicaea in Bithynia but lived in Rhodes and Alexandria. His theory of the movements of the sun and moon were very important, especially for those who wished to construct calendars. He rediscovered the precession of the equinoxes and calculated it to be 36'' per year. He gave the length of the tropical year as 365 days, 5 hours, 55 minutes, 12 seconds; and of the synodic month as 29 days, 12 hours, 44 minutes, and 3-1/3 seconds.

Hipparchus explained the irregular movements of the sun and moon by eccentrics and epicycles, and refuted the idea of Eudoxus

that a year equaled $365\frac{1}{4}$ days, the quarters being added by means of an intercalary day in every fourth year. According to Ptolemy¹² this year was too long by $1/300$ th part of a day, so that at the end of 300 years the solstice would precede the end of the year by one whole day, therefore in order to adjust the calendar one day should be subtracted at the end of every 300 years. But according to al-Battani one day should be dropped in every 100 years, the year was thus considered to be too long by 14.4 minutes, a calculation which is really nearer the truth than that of Hipparchus or Ptolemy. Al-Battani¹³ was one of the best astronomers of his period and was so recognized by his contemporaries and by Arab and western European writers even as late as Regiomontanus. In the twenty-seventh chapter of his De scientia stellarum he says that the Babylonian and Egyptian sidereal year consisted of 365 days, 50 minutes, and 40 seconds. In calculating this length, al-Battani

that it moved in an orbit inclined to the ecliptic. However, he recognized only one inequality in the moon's motion, leaving the discovery of evection to Ptolemy. Dreyer, op. cit., pp. 162-75; Sarton, I, 193.

¹²Ptolemy was born in Egypt and spent most of his life in Alexandria; he was still living in 161 A.D. His work, called the Almagest by the Arabs and Grosseteste, is an encyclopedia of astronomy upon which most scientists based their calculations even as late as the sixteenth century, although a number of writers from the time of al-Bitruji on, disagreed with some of his ideas. A great deal of his work was based upon that of Hipparchus, but he made many improvements, especially in regard to the latter's planetary system. However, in his solar theory, Ptolemy followed Hipparchus very closely and did not allow for the fact that in the 300 years between the time of Hipparchus, and himself there was a miscalculation of $5\frac{1}{2}^{\circ}$, due to the precession of the equinoxes and the displacement of the line of apsides. In working out his theories of the motions of the sun, moon, and planets, Ptolemy used a complicated system of eccentrics as well as epicycles, later criticised by al-Bitruji and Grosseteste. But it is important to note that these were used merely to represent mathematically the positions of the planets, and not to give the real, physical system of the universe. Dreyer, op. cit., pp. 165-70; 205-30. Sarton, op. cit., I, 272-78.

¹³Al-Battāni, known to western writers as Albategnius, was like Thebit, born in Harran. Nothing is known of his childhood or private life except that his father was a famous manufacturer of astronomical instruments. Between the years 878-918 he was in al-Raqqā on the Euphrates where he made many observations and wrote astronomical treatises, the most important being De scientia stellarum.

reckoned from the equinoxes and not from the solstices, trusting especially the autumnal "equinox because the air of autumn was purer."¹⁴ The length of the year which al-Battani gave is proved to be better than that of Hipparchus by the fact that the "winter solstice now precedes the day of the birth of our Lord by about as many days as the number of periods of 100 years which have passed since his birth"¹⁵ although according to the Scriptures Christ was born in the winter solstice.

The best calculations, however, are those made by Thebit ibn Qurra¹⁶ who determined the length of the year by the motion of the sun in its relation to the stars.¹⁷ Grosseteste says that this is more correct because the revolution of the sun from solstice to solstice, or from equinox to equinox is not always con-

¹⁴Chapter I.

¹⁵Ibid.

¹⁶He was born in 836 in Harran in Mesopotamia, a city famous from ancient times as a center of Greek and Oriental learning. In the time of Thebit it was a city of Sabians noted as scientists and philosophers. In Harran Thebit was a banker, mathematician and astronomer. He was taken to Bagdad by Muh ibn Musa where he became a celebrated translator of Greek and Syriac manuscripts, and the center of a learned group at the court of al-Mutadid. He translated some of the works of Apollonius of Perga, Archimedes, Euclid and Theodosius, and revised and corrected the translation of the Almagest which had been made by Isaac ibn Honsin in 817. He was interested in music, botany, medicine, meteorology, astronomy and mathematics. Dreyer, op. cit., p. 276; Duhem, op. cit., II, 117-19, 238-46; Sarton, op. cit., I, 599-600.

¹⁷I.e. a sidereal year. Scattered throughout the libraries of Europe there are many copies of a treatise called De motu octavae sphaerae ascribed by most authorities to this Thebit. Duhem gives a number of arguments to show that this particular article was written by Arzachel who lived in Spain in the eleventh century. Contemporary Arabic writers assigned it to Arzachel; also, al-Battani's work is quoted therefore it was supposedly written a few months after the death of Thebit. However, Grosseteste, who knew the writings of Arzachel, assigns the theory of the movement of the eighth sphere to Thebit and quite evidently is quoting from the De motu octavae sphaerae in chapter I. Roger Bacon says in his Compotus, 98, that Thebit and Arzachel each had the same theory which each had expressed in a treatise called De anni solaris. In the Opus maius (Bridges I, 394) Bacon says Thebit corrected the works of Ptolemy and others by information which he gained from Indian sources.

stant, but that a revolution from one fixed star to another fixed star is always constant. The length of the year given by Thebit is $365\frac{1}{2}$ days and 23 seconds of a day. Thus at the end of 156 years the sun will "be behind the star A by as great a distance as the sun can go in one day minus 12 seconds of a day."¹⁸ To correct the calendar it would then be necessary to add one day every 156 years, but this addition then causes the sun to go beyond star A 12 seconds of a day in every period of 300 years, thus one day must be subtracted every 46,800 years. To account for the imaginary trepidation of the equinoxes, the author of the *De motu octavae sphaerae* introduced a ninth sphere (*primum mobile*), without stars, which completed its revolution once every 24 hours and by its motion moved the eighth sphere. In this ninth sphere he imagined a fixed ecliptic whose plane intersected the plane of the fixed equator at two equinoctial points which were the fixed heads of Aries and Libra. The angle between these two planes was according to him, $23^{\circ} 30'$, a calculation which was much better than that of Ptolemy. The eighth sphere, i.e., the sphere of the images, is moved by the ninth one, but also had its own proper motion which he explained by passing another plane, that of the movable ecliptic, through the same center. On this plane were two rectangular diameters with four points, two of them, a and b, diametrically opposed to each other, representing the movable head of Aries and the movable head of Libra; the two other points, c and d, also diametrically opposed were the movable heads of Cancer and Capricorn. The movable head of Aries describes a circle whose center is A and the movable head of Libra describes one whose center is B. However, the heads of Cancer and Capricorn always remain on fixed ecliptics moving backward and forward $10^{\circ} 45'$. Thus he has imagined a movable ecliptic which rises and falls on the fixed ecliptic, while the equinoctial points have a movement of access and recess. The author goes on to say that this movement of the eighth sphere is common to all stars, therefore the apogee of the sun and the auges or apogees of the eccentrics of the planets follow exactly the movement of the fixed stars, which is contrary to the opinion of Ptolemy that it does not move. He says that the sun sometimes reaches its greatest declination in Cancer and sometimes in Gemini. Thus he notes the change in direction and amount of the motion of the equinoxes which he says is now 1° in 66 years instead of 1° in 100 years as Ptolemy calculated. From the com-poti¹⁹ of both Bacon and Grosseteste we may conclude that it was this same Thebit who determined the length of the anomalistic

¹⁸Chapter I.

¹⁹Bacon, Chapter XX. Grosseteste, Chapter I.

year, (the length of time the sun takes to return to its own apogee) to be 365 days, 6 hours, 12 minutes, 9 seconds; and the sidereal year to be 365 days, 6 hours, 9 minutes, 12 seconds. These reckonings are practically the same as the ones accepted to-day, the anomalistic year being 365 days, 6 hours, 13 minutes, and 54.9 seconds; and the sidereal year 365 days, 6 hours, 9 minutes, and 10.7 seconds.

The second important problem with which Grosseteste has to deal, is that of the determination of new moon days, which were arranged in the ecclesiastical calendar in a cycle of nineteen years. Grosseteste shows, by a comparison with the Arabic cycle of thirty years, that the cycle of new moon days is not really completed in nineteen Julian years, and that by the end of 4,256 years the error in the reckoning of the age of the moon would amount to fourteen entire days.

Thus instead of the cycle of nineteen Julian years, the Arabic cycle of thirty years as given by al-Zārqālī²⁰ in the Tables of Toledo should be used in constructing a table of new moon days. According to the calculations of Hipparchus, Ptolemy, and al-Zarqali, the length of an equal lunation is 29 days, 31 minutes, 50 seconds, 8 thirds, 9 fourths, and 20 fifths. Thus 12 equal lunations contain 354 days and 22 minutes of a day and complete their cycle only at the end of thirty Arabic (lunar) years, i.e. in 10,641 days, because it takes this space of time for the sun and moon, each following its mean course to pass from one conjunction on the line of the meridian of Paris to a second conjunction on the same meridian.

Not only was the nineteen year cycle incorrect but also the cycle of epacts by which the age of the moon at the beginnings of our months could be found. In place of the cycle of epacts should be used the Arabic cycle of thirty years, for the first day of each month of the Arabic year is the day of the conjunction of the sun and moon, each following its mean course, therefore, by knowing the beginnings of the Arabic months we know the beginnings of the new moon days. For this reason Grosseteste includes in his Computus (in chapter 5) al-Zarqali's method of finding Arabic years and months from the years of our Lord.

However, when he used this cycle to determine the date of Easter, Grosseteste does not reckon the moon to be the first on the day of its conjunction with the sun, but on the following day

²⁰(c.1029-1087). Spent most of his time in Cordova. He invented the improved astrolabe, saphae Arzachelis. Was the editor of the Toledan Tables. Duhem, op. cit., II, 246-59; Sarton op. cit., I, 758-59.

"where it is possible that its ascension from the sun first appears, otherwise the moon would be called the fifteenth when it was really the day of the full moon" (lunae XIV).²¹

Because of these errors in the calculation of the length of the year, and in the period of an equal lunation, the Church had not been able to determine correctly the days of Easter and the other movable feasts. As Grosseteste says, they thought the spring equinox should come twelve days before the calends of April when, according to the Tables of Toledo "founded upon the length of the year and the motion of the eighth sphere given by Thebit"²² it really should come on the day before the ides of March. This gradual change in date is due to the precession of the equinoxes concerning which, he says, Rabanus and the founders of the calendar were entirely ignorant. The second error, that the moon is never full when it is marked the fourteenth, is shown by the lunar eclipses. This miscalculation is due to the fact that the Church does not know the true length of an equal lunation.

Although Grosseteste realized the inaccuracies of the ecclesiastical system of reckoning time advocated by the early computists, nevertheless he included in his treatise a full discussion of each of the topics always found in a Computus. Because of this some critics have contended that although Grosseteste shows a fairly accurate knowledge of the best Greek and Arabic astronomical data, eventually he always goes back to the method of calendar reckoning still in use in the Roman Church. Baur²³ says that no writer before Bacon dared to advocate a real breaking away from the current methods of calculating the church festivals. In the light of Grosseteste's own statement, repeated in several chapters, this is an unfair criticism. He gives the Greek and Arabic astronomical theories and calculations by which he says the calendar may be corrected. Then just before starting his discussion of the ecclesiastical system he says, "From the preceding it is clear that the incorrectness of our calendar is shown" in such and such a case, "however because the Holy Church is still using this system it will now be explained."²⁴ One can almost hear the good bishop sigh when he has to begin his explanation of the long and intricate ecclesiastical methods of calculating Easter and the other movable feasts, when he has already told us that this calendar can be reformed only by adopting and improving upon the Greek and Arabic calculations. He gives the ecclesiastical system so that any priest who wishes to find the date of

²¹Chapter IV.

²²Chapter XI.

²³Op. cit., p. 162.

²⁴Chapter I, III, IV, XI.

Easter and the other feasts may do so according to the only method which is still acceptable. From what we know about Grosseteste's general attitude toward the Church, we may be pretty certain that he was not afraid of criticising ecclesiastical custom, even one so firmly established as the method of finding Easter.

In his discussion of the ecclesiastical methods of reckoning time, Grosseteste deals first with the solar cycles, the cycles of Dominical Letters, concurrents, and solar regulars which were used to arrange the days, weeks and months of the tropical year. The solar cycle, or cycle of Dominical Letters had been established so that one could determine in advance for any given year the relation of any week day to any day of the month, and the dates of the Sundays in any given year. To every day of the year was assigned one of the first seven letters of the alphabet, with the exception of the 29th of February which had no letter. Thus every Sunday of any given year would have the same letter of the alphabet except when there was an intercalary day. Because the year 1 A.D. was assumed to be the tenth year of the cycle, to find the number of any year in the cycle, add nine to the date and divide by twenty-eight, the remainder showing the number of the year. If there is no remainder, the number is twenty-eight. This cycle is finished in twenty-eight years; because twenty-eight is the product of four, the number of years in the intercalary period, and seven, the number of days in a week.

Grosseteste includes in his Computus a discussion of concurrents although they are not ordinarily used in Easter tables. The concurrent number of a year is obtained from the number of extra days above the number of complete weeks of the previous year. For instance, the year which has one extra day has one for a concurrent because seven, the number of days in a complete week is subtracted from the eight. This solar cycle is also finished in twenty-eight years.

With these concurrents are used the solar regulars to show on which week day each month begins. In the first year of the establishment of the calendar, the first day of March was the fifth week day, therefore the regular of that March was five. Since it is also known that the Dominical Letter of the first of March in that year was D, the letter D thus represents the fifth week day. From this the regulars of each month of any given year can be found. Then by adding the concurrent of any year to the regular of any month of that year, the sum, if less than seven, shows the number of the first week day of that month; if greater than seven, seven is subtracted, and the remainder is the number of the first week day of that month.

To arrange solar cycles was a fairly simple matter, but it

was much more difficult to devise the lunar-solar cycles which were necessary for the determination of Easter and the other movable feasts of the ecclesiastical calendar, so that Grosseteste spends a great deal of time in explaining and criticising the latter cycles. The most important of these was the nineteen year cycle which was used to connect the lunar month and the solar year. At the end of nineteen years the new moons will occur on the same days in any two years which have the same number in the cycle, thus one could find out in advance all the days of new moons for any given period of time, and especially the dates of the vernal new moons from which Easter days could be determined. In order to find out what number in the cycle any given year has, add one to the date and divide by nineteen, the quotient being the number of cycles which have elapsed since 325 A.D., and the remainder is the Golden Number. When the remainder is 0, the year is the nineteenth in the cycle.

These new moon days could also be found by the cycle of epacts. The non-intercalary solar year has 365 days, and the lunar only 354, therefore if a new moon comes on the first of January of any year, it will be eleven days old on the first of January of the next year, and so on, these numbers of the excess days representing the epacts of those years. When the number is greater than thirty, thirty is subtracted and the remainder is the epact of that year. In this table of epacts is also marked the lunar regulars, calculated from the numbers of the age of the moon in the beginnings of the months in the first year of the establishment of the calendar.

According to Grosseteste, all of these cycles are incorrect and only the cycle of thirty Arabic years should be used in making a calendar. It was because of these errors that the Church was having trouble in finding the proper dates for Easter and the other movable feasts. These festivals could not come on the right days of the month or in the proper seasons of the year if there was not a true co-ordination between the lunar month and the solar year.

BIBLIOGRAPHY

Original Sources, MS

- Anonymous, Massa Compoti, British Museum, Vespasian A II.
Gerland, Compotus initantis Bedam, Vespasian A IX, 2, British Museum.
Gordianus, Compotus, Ms. Vindonob, 5239.

Original Sources, Printed

- Al-Battani, Opus astronomicum, ed. by C.A. Nallino, in Pubb. del reale Osserv. di Brera, Milan, 3 parts, 1899-1903.
Alcuin, Letters, Jaffe, Monumenta Alcuiniana, VI, Berlin, 1873.
Annales Laurissenses et Einhardi, MGH. SS, I, 171.
d'Ailly, Peter, Exhortatio ad concilium generale Constantiense super correctione calendarii, in J.D. Mansi, Sacrorum conciliores Nova, XXVIII, Venice, 1785.
Bacon, Roger, Opus maius, ed. by J.H. Bridges, Oxford, 1897.
Bacon, Roger, Compotus, in Opera hactenus inedita Rogeri Baconi, Fasc. VI. ed. by Robert Steele, Oxford, 1926.
Baur, L, Die philosophischen Werke des Grosseteste, Münster, 1912.
Bede, De temporum ratione, Opera omnia, Vol. VI, ed. by J.A. Giles, London, 1843-44.
Cassiodorus, Institutiones, in Migne, Pat. lat. LXX, 1105-1120.
Eusebius, Historia ecclesiae, in Migne, Pat. graec. XX.
Gerland, Abacus, ed. in Boncompagni, Bull. di storia delle scienze, X, Rome, 1877.
Helpericus, Compotus, Migne, Pat. lat. CXXXVII.
Keroli Magni Capitulari, in MGH. LL. II.
Maurus, Rabenus, Compotus, in Stephan Baluzo, Miscellanea. II, 62-84, 7 vols., Paris, 1618-1715.
Isidore of Seville, Etymologiae, in Migne, Pat. lat. LXXXI.
Ptolemy, Composition mathématique, ed. and trans. by Halma, 1927.
Philip of Thaan, Li cumpoz, ed. by E. Mall.
Scottus, Marianus, Chronicon, MGH. SS. V, 481ff.
Scottus, Marianus, Compotus, Migne, Pat. lat. CXLVII, 601-802.
Victor of Aquitaine, Calculus, ed. by G. Firdeluin, in Bull. di bibliogr. e di storia d scie. mat. IV, Rome, 1871.

- Acht, W., Die entstehung des Jahresanfangs mit Ostern. Dissertation, Berlin, 1908.
- Bond, J.J., Handy-book of rules and tables for verifying dates with the Christian era, 4th ed., London, 1889.
- Boll, F., Sphaera, Leipzig, 1903.
- Cantor, M., Geschichte der Mathematik, 3rd ed., Leipzig, 1914.
- Carton, Raoul, L'experience physique chez Roger Bacon. Thesis, Paris, 1924.
- Charles, E., Roger Bacon, Bordeaux, 1861.
- Dreyer, J.L.E., Planetary systems, Cambridge, 1906.
- Duhem, P., Le systeme du monde, 5 vols., Paris, 1914-1917.
- Felten, J., Robert Grosseteste, Freiburg, 1887.
- Gaskoin, C.J.B., Alcuin, Cambridge, 1904.
- Ginzler, F.K., Handbuch der mathematischen und technischen Chronologie, 3 vols., Leipzig, 1914.
- Grotefend, Taschenbuch der Zeitrechnung des Deutschen Mittelalters und der Neuzeit, 3rd revised edition, Hanover, 1910.
- Grotefend, Handbuch der historischen Chronologie des deutschen Mittelalters, Hanover, 1872.
- Hampson, R.T., Medii Aevi Kalendarium, London, 1844.
- Haskins, C.H., Studies in Medieval Science, Cambridge, 1927.
- Haskins, C.H., "Michael Scot and Frederick II," in Isis, IV, 1922.
- Honigman, E., Die sieben Klimata, Heidelberg, 1929.
- Hilgenfeld, A., Der Paschastreit der alten Kirche, Halle, 1860.
- Kaltenbrunner, F., "Die Vorgeschichte der gregorianischen Kalenderreform," Sitzsb. der K. Ak. d. Wiss., phil.-hist. Kl., 82, Vienna, 1876.
- Ideler, L., Handbuch der mathematischen und technischen Chronologie, 2 vols., Breslau, 1883.
- Krusch, Studien zur Christlichen-mittelalterlichen Chronologie, 1881.
- Lindhagen, A., "Die neumondtafel des Robert Lincolenses," in Archiv. für matematik, 1916.
- Little, A.G., ed. Roger Bacon Essays.
- Luard, H.R., Preface to the Letters of Grosseteste, London, 1863.
- Manitius, M., Lateinische Literatur des Mittelalters, 2 vols.
- Manitius, K., Des Claudius Ptolemaeus Handbuch der Astronomie, Leipzig, 1912.
- Pegge, S., The Life of Robert Grosseteste, London, 1793.
- Petau, D., De doctrina temporum, Paris, 1627.
- Philip, Alexander, The Calendar, Its History, Structure, and Improvement, Cambridge, 1921.

- Poole, R.L., "The Earliest Use of the Easter Cycle of Dionysius," in English Historical Review, XXXIII, 62, 1918.
- Poole, R.L., "The Beginning of the Year in the Middle Ages," in Proceedings of the British Academy, X, 1921.
- Sarton, Introduction to the History of Science, 2 vols., Baltimore, 1927-32.
- Sandys, J.E., History of Classical Scholarship, Cambridge, 1906.
- Schwartz, E., "Christliche und jüdische Ostertafeln," in Abhand. d. Konigl. Gesellschaft d. Wisses. zu Gottingen, phil.-hist. Kl. N. Folge VIII, nr. 6. Berlin, 1905.
- Steinschneider, M., "Etudes zur Zarkeli," in Bullettino, XIV, XVI-XVIII, XX, 1181-87.
- Stevenson, F.S., Robert Grosseteste, London, 1889.
- Suter, H., Die Mathematik auf den Universitäten des Mittelalters.
- Tannery, P., Recherches sur l'histoire de l'astronomie, Paris, 1893.
- Thompson, J.W., "Introduction of Arabic Science into Lorraine," in Isis, XII, 184ff., 1929.
- Thorndike, L., A History of Magic and Experimental Science, 2 vols. New York, 1923.
- Traube, L., "Computus Helperici," in Neues Archiv, XVIII, 73-105, 724ff.
- Wordsworth, C., The Ancient Kalendar of the University of Oxford, Oxford, 1904.
- Wallace, Dom W., St. Edmund of Canterbury, 1893.

